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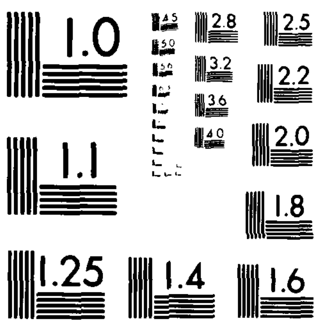

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

VERIFICATION OF A WAVEMAKING RESISTANCE REDUCTION METHOD BY BABA

by

Steven C. Fisher

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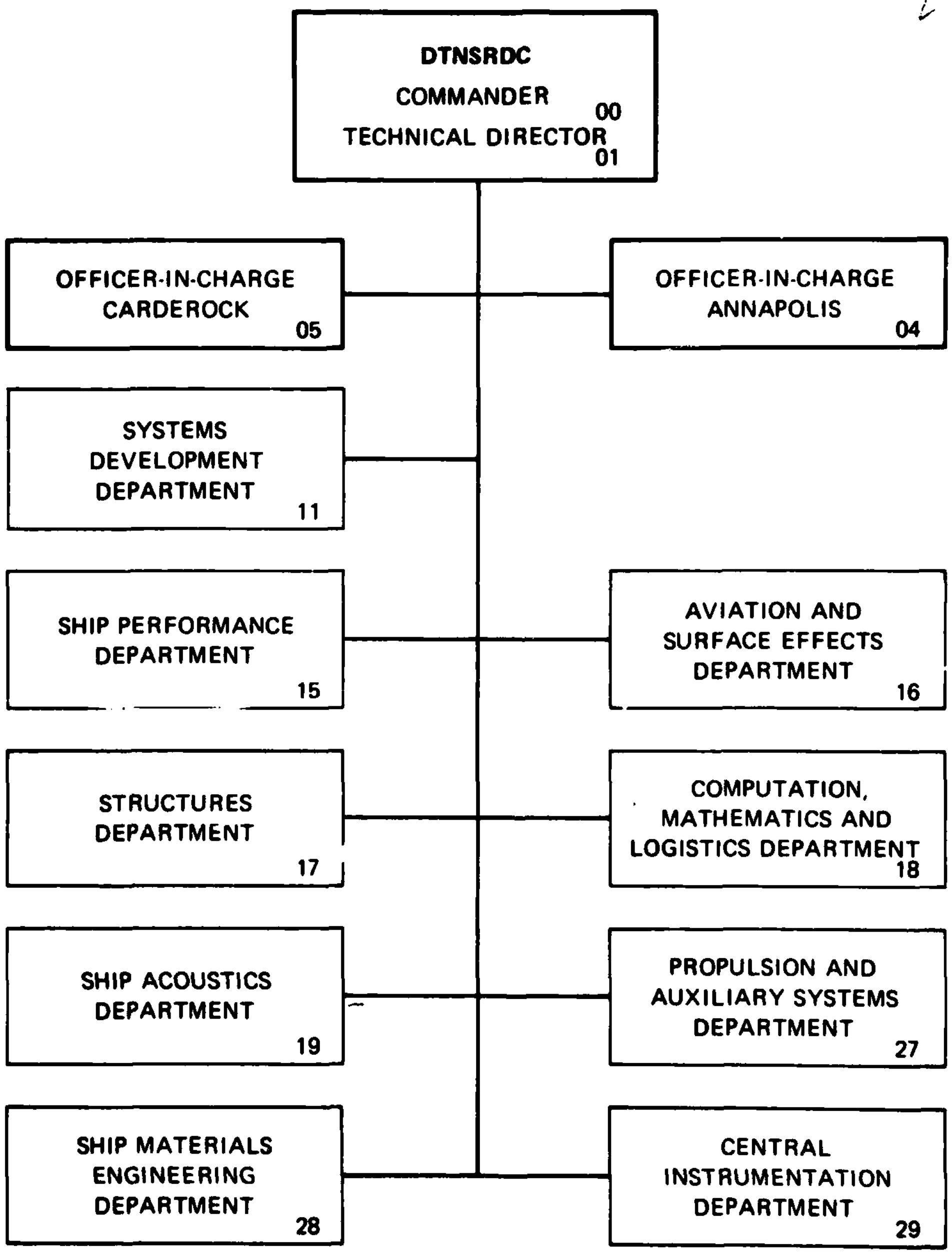
SHIP PERFORMANCE DEPARTMENT

DEPARTMENTAL REPORT

MARCH 1981 DTNSRDC/SPD-0990-01

VERIFICATION OF A WAVEMAKING RESISTANCE REDUCTION METHOD BY BABA

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



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A series of resistance and longitudinal wavecut experiments were performed on Model 5079 (AKA 113) to verify a theoretical empirical method developed by Baba for minimizing wave resistance by adding an optimum thin ship to an existing ship. The results indicate that the model developed using Baba's method shows lower resistance than the original model above the optimization speed but greater resistance below the optimization speed. A further improvement of Baba's method is necessary to obtain a balanced reduction in the resistance in the speed range of interest.

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NOMENCLATURE

SYMBOL	DESCRIPTION
A	Sectional area
AX	Maximum Sectional Area
B	Beam
C_B	Block Coefficient
C_R	Residuary Resistance Coefficient
C_W	Wave - Cut Resistance Coefficient
F_n	Froude number
L	Ship or Model Length
P_E	Effective Power
x	Distance along the centerline from the forward perpendicular, positive aft
X_e	Distance to the aftmost point of the thin ship (nondimensionalized by L)
X_s	Distance to the forward most point of the thin ship (nondimensionalized by L)
Y	Transverse distance from the model centerline to the waveprobe

ENGLISH/SI EQUIVALENTS

ENGLISH	SI
1 inch	25.400 millimetres [0.0254 m (metres]
1 foot	0.3048 m (metres)
1 foot per second	0.3048 m/sec (metres per second)
1 knot	0.5144 m/sec (metres per second)
1 pound (force)	4.4480 N (Newtons)
1 degree (angle)	0.01745 rad (radians)
1 horsepower	0.7457 kW (kilowatts)
1 long ton	1.016 tonnes, 1.016 metric tons, or 1016 kilograms

ABSTRACT

A series of resistance and longitudinal wavecut experiments were performed on Model 5079 (AKA 113) to verify a theoretical-emperical method developed by Baba for minimizing wave resistance by adding an optimum thin ship to an existing ship. The results indicate that the model developed using Baba's method shows lower resistance than the original model above the optimization speed but greater resistance below the optimization speed. A further improvement of Baba's method is necessary to obtain a balanced reduction in the resistance in the speed range of interest.

ADMINISTRATIVE INFORMATION

This project was authorized and funded by the Naval Material Command (NAVMAT) Ship Performance and Hydromechanics Program under Program Element 62543N, Subproject Number 43-421-001, Work Unit Number 1-1507-101-65.

INTRODUCTION

A series of resistance and longitudinal wavecut experiments were performed in the deep water basin at DTNSRDC on Model 5079-1 to experimentally verify a theoretical-empirical method developed by Baba[1*] for reducing wave resistance. Baba's method uses longitudinal wavecut information to find an optimum thin ship that, when added to the original thin ship, will minimize the wave-cut[**] resistance.

An initial series of resistance and longitudinal wavecut experiments were performed on Model 5079. Model 5079 represents the AKA 113, a fine single screw ship with a slightly protruding 3% bulb. The information from the wavecuts were input into a computer program based on Baba's method, HULIMP[2,3] to develop the optimum thin ship at the ship-scale speed of 22 knots (11.3 m/s). The remaining wavecut data taken at other speeds were used to predict the off-design performance of the "optimized" hull form.

Baba's method can optimize a given hull form by adding a thin ship along its entire length. However, the effect of the thin ship along the afterbody is overpredicted due to the thicker boundry layer at the stern. Because of this, the optimization is here limited to the forebody. The thin ship extends from 2.5%L forward of the forward perpendicular (to represent a bulb) to amidships.

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* Numbers indicate references listed on page 10.

**Wavemaking resistance calculated from far-field waveheight measurements (wavecuts).

Also, since the draft and displacement are to remain constant, the net volume of the thin ship is set at zero. A new forebody, developed by adding this thin ship to the existing forebody, was then added to the existing afterbody to create Model 5079-1. Model 5079 is referred to in this report as the original hull, and Model 5079-1 is referred to as the optimized hull.

A final series of resistance and wavecut experiments were performed on Model 5079 and Model 5079-1. The experiments with the model with the new forebody (5079-1) were to verify the earlier predictions, and the experiments with the model with the original forebody (5079) were to check the repeatability of the earlier predictions.

Presented in this report are the original and final predictions of the change in wave resistance due to adding an optimized thin ship to the existing ship with the original forebody. A comparison of the predicted change in resistance to the actual change in resistance is included.

EXPERIMENTAL ARRANGEMENT

Model 5079 was constructed of wood to a scale ratio of 32.5. The model was originally constructed in one piece, but later was cut apart at amidships to connect the new "Baba" forebody to the afterbody (Model 5079-2). Table 1 contains the principal dimensions of the ship and models, and Figure 1 shows the lines drawings of the models. The sections were joined at amidships using aluminum bulkheads.

The models were fully appended except for propellers during the experiments. The models were ballasted to the full load draft of 0.244 m (0.802 ft), and displacement of 554 kg (1221 lbs). This corresponds to a full scale draft of 7.925 m (26 ft), and displacement of 18954 tonnes (19257 tons).

The experiments were conducted in the deep water basin at DTNSRDC. A resistance wire waveprobe was used to obtain waveheight data. The data was digitized and stored on magnetic tape for later analysis using the Centers' CDC 6000 series computer system.

DISCUSSION

Initial Experiments and Predictions

As an initial step to the hull optimization technique developed by Baba, longitudinal wavecut experiments were performed on Model 5079, representing the AKA 113. The wavecuts were taken at Froude numbers (F_n) of 0.203, 0.229, 0.254, 0.279, 0.305, and 0.330 (corresponding to the ship speeds of 8.23, 9.27, 10.30, 11.33, 12.36, 13.38 m/s; or 16, 18, 20, 22, 24, and 26 knots).

Figure 2 shows the wave - cut resistance coefficient (C_W) curves for the original model, the optimized model, and the predicted results for the optimized model. The wave - cut resistance is calculated using waveheight data from a longitudinal wavecut. Since Babas' method optimizes by minimizing wave - cut resistance, the greatest benefits are gained when optimizing at a speed at which the model has a large wave - cut resistance. At the original design speed of $F_n = 0.254$, the original model C_W value is small compared to the C_W values at the higher speeds. The speed selected to optimize at, $F_n = 0.279$, was chosen because of the corresponding large C_W value while still being relatively close to the original design speed. It should be noted that because it is necessary to have a wavecut at the speed selected for the optimization, the choice of the optimizing speed was limited to the speeds used in the initial wavecut experiments.

The computer program based on Baba's method, HULIMP, allows certain constraints to be placed on the optimum thin ship. These constraints include volume, beam at admidships, number of terms in the sine series used to find and describe the thin ship, and the endpoints of the thin ship relative to the hull. The net volume of the thin ship was set at zero to keep the displacement of the optimized hull the same as that of the original hull. The thin ship beam at amidships was also set at zero to keep the admidships section constant. The number of terms in the sine series describing the thin ship was determined by the equation[2] $N = 20 \times (X_e - X_s) \times L$.

An analysis to determine the length of the optimizing thin ship was performed. Two techniques were considered: the thin ship added to just the forebody, and the thin ship added along the entire length of the hull. The predicted results showed that at $F_n = 0.279$ the C_W values decreased from

1.019×10^{-3} with the original hull to 0.636×10^{-3} and 0.615×10^{-3} with the forebody and full length optimum thin ships, respectively. Since the effects due to a thin ship added to the forebody are more accurately predicted than the effects due to a thin ship added along the afterbody, and the decrease in the predicted C_W values for the two thin ships was comparable, the selected thin ship was limited in length to the forebody. The thin ship was also extended slightly forward of the forward perpendicular (2.5% L) to simulate the effect of adding a larger, more protruding bulb.

During the initial phase of the project, the computer program HULIMP was modified to allow the input of an arbitrary shaped thin ship[3]. This change makes it possible to predict the wave - cut resistance of a hull and thin ship combination at speeds other than the thin ship design speed. The predicted C_W values for the new optimized hull are shown in Figure 2. The predicted C_W values for the optimum hull are lower than those for the original hull above $F_n = 0.270$. The predicted C_W curve has a number of humps and hollows; this is not unexpected since Baba's method uses Mitchell's equation.

Optimized Hull Design

To develop the optimized hull sectional area curve, the sectional area of the thin ship was added to the original hull sectional area curve. Figure 3 shows the sectional area curves of the original and optimized hulls. This new sectional area curve was smoothed. The forebody stations were redrawn to match the new sectional area curve. At the bow, there was an increase in the sectional area. Part of the increase in volume at the bow was used to develop a larger bulb. Aft of station 3, the new stations took the shape of sections of the original forebody which had the same sectional area.

The new forebody was crossfaired, with emphasis placed on keeping the sectional areas constant. It should be noted that the final forebody stations were fair, but the waterlines were not as fair as is usually acceptable by normal naval architectural standards. However, the waterlines are smooth. The waterlines were not faired further because it would have altered the sectional areas significantly, which would have altered the shape of the actual thin ship by an unacceptable amount. Since this project was to be a verification of Baba's method, it was important to keep the optimum and the actual thin ship shape as alike as possible.

The bow profile shape was based on a combination of a shape consistent with the stations and waterlines, and a bulb projection beyond the forward perpendicular of X/L = -0.025.

Comparison of Predictions and Results

The predicted and actual C_W curves for the optimized hull (Model 5079-1) are shown in Figure 2. The "predicted" C_W values are calculated by adding the thin ship theoretical wave spectra to the wave spectra (derived from wavecut data) of an existing hull. The actual C_W values come from wavecut data taken during the resistance experiments with Model 5079-1 which represents a combination of the original hull and thin ship. If the humps and hollows in the predicted C_W curve are flattened out, the predicted and actual C_W curves would lie very close. The humps and hollows in the predicted C_W curve probably are a result of the use of Mitchell's equation in Baba's method.

Because the design speed corresponds to a hollow in the predicted optimum hull C_W curve, the predicted C_W value at the design speed is noticeably lower than the actual optimum hull C_W value, i.e., $C_W = 0.68 \times 10^{-3}$, compared to 0.90×10^{-3}. Also, the predicted optimum hull C_W curve crosses the original hull C_W curve at a lower F_n than the actual optimum hull C_W curve does; i.e., $F_n = 0.271$ compared to 0.275. Again, most of the differences between the actual and predicted optimum hull C_W curves are due to the humps and hollows in the predicted C_W curve.

The C_R curves for the original and optimized hulls are shown in Figure 4. The C_R curves follow the trend of the C_W curves, with the optimized hull showing a decrease in C_R values compared to the original hull at higher speeds. However, while the optimized hull had a lower C_W value than the original hull at the optimization speed of $F_n = 0.279$, the optimized hull had a higher C_R value than the original hull at the design speed; i.e., $C_R = 1.90 \times 15^{-3}$ compared to 1.79×10^{-3}. This is due to the C_R curves crossing at a higher speed ($F_n = 0.283$) than the optimization speed.

The effective power (P_E) curves for the original and optimized hulls are shown in Figure 5. Since the wetted surface and displacements of the two hulls are virtually the same, the differences between the original and optimum hull P_E curves are due to changes in the residuary resistance alone, The optimized hull has a higher P_E value than the original hull at the design speed ($F_n = 0.279$), 13540 KW (18150 hp) compared to 13090 KW (17550 hp), respectively. At slightly higher speeds (above $F_n = 0.283$), the P_E values for the optimized hull are lower than those for the original hull.

It is not surprising that the speed at which the optimum hull has a lower wave - cut resistance than the original hull differs from the speed at which the optimum hull has lower P_E and C_R values than the original hull. The reason is that an optimized hull form solely based on the wave - cut resistance could result in changes in the other components of the resistance, which, in turn, could cause a change in the characteristics of the overall residuary resistance.

Figure 6 shows the predicted C_W curves for a thin ship and hull combination optimized at various speeds. The thin ship and hull combinations optimized at F_n = 0.203, 0.228, 0.254, 0.279, 0.305, and 0.330 are denoted as Hulls A to F, respectively. The thin ships are shown in Figure 7. The lines for Hulls A to F were never generated. It should be noted that, while Hull D is optimized at the same F_n as the optimized hull, F_n = 0.279, the predicted C_W curves and thin ship shapes differ from the optimized hull. This is a result of the fact that the optimized hull was developed by using the data from the initial wavecut experiments, while the optimizing thin ships for Hulls A to F are derived using data from the final series of wavecut experiments.*

The C_W curves for Hulls D to F are somewhat similar in shape, with their peaks and troughs occurring at approximately the same speeds. The corresponding thin ships also have strong similarities. The thin ships have a large amount of positive volume at the bow, and a large decrease in volume in the middle of the forebody. Since the thin ship for Hull C (F_n = 0.254) has a negative volume at the bow, it is not surprising that its C_W curve differs greatly from those of the optimized hulls at the higher speeds.

Both the thin ships and the C_W curves for Hulls A and B (F_n = 0.203 and 0.228) are somewhat similar in shape. Both of the thin ships have positive volume at the bow and negative volume at the middle of the forebody. Their lower C_W values (compared with Hulls D to F) at the lower speeds are probably due to the smaller alteration of forebody volume from the original hull form.

Since the optimizing thin ship at F_n = 0.254 differs greatly in shape from the other thin ships, care should be exercised in selecting a hull optimized at this speed. It may be desirable to obtain more wavecut information at nearby speeds (say F_n = 0.268 or F_n = 0.265) to examine the trend in thin ship shape near this speed.

*The final series of wavecut experiments were conducted to confirm the previous results, and were believed to be slightly more reliable for the purpose of comparing the resistance characteristics at different speeds of optimization.

The results of the wavecut experiments with the optimized hull indicate that the predicted C_W curve is similar in shape to the actual C_W curve if the humps and hollows in the predicted C_W curve were smoothed. A similar smoothing, done by hand, was applied to the C_W curves shown in Figure 6 to see how the C_W curves could be affected. These "smoothed" C_W curves for Hulls A to F are shown in Figure 8.

The predicted C_W curve for hull B (F_n = 0.228) is much lower than the predicted C_W curve for Hull D (F_n = 0.279) up to F_n = 0.280, and is just slightly higher above that Froude number. On the basis of the curves shown in Figure 8, the original hull should be optimized using the optimizing thin ship at F_n = 0.228. Further, the predicted C_W curves for Hulls C and F (F_n = 0.254 and F_n = 0.330) indicate that no hull should be optimized at th e speeds since these curves never have the lowest C_W values compared to the other C_W curves at any speed.

The above indicates that if the C_W curve smoothing assumption is correct, the most desirable thin ship shape to optimize a hull can be different from what is indicated by the original (unsmoothed) predicted C_W curves. A much larger data base will be needed to validate the smoothing assumption.

Repeatability

Since wavecut experiments were performed on the original hull (Model 5079) during the initial and final series of experiments, it is possible to examine the repeatability of Baba's method. This is a function of the repeatability of the wavecuts themselves. However, instead of analyzing the wavecuts for their differences, the changes in the optimum thin ships for various speeds from the initial to the final experiments will be examined.

Figures 8 to 13 show the thin ships optimized at various speeds using wavecut data from both the initial and final series of experiments. Two wavecuts were analyzed from both the initial and final experiments for each speed. In most cases, the differences between the thin ships from each series of experiments are about the same size as the differences between the shapes of the thin ships from the initial and final experiments. The thin ships optimized at F_n = 0.207 and 0.279 did not show as good agreement in shape as did the other thin ships. The differences in thin ship shape and size at F_n = 0.203 are not surprising since

it is difficult to measure the model wave system at low speeds due to the small wave amplitudes. The difference between the shapes of two sets of thin ships optimized at $F_n = 0.279$ are surprising since they are larger than the differences observed in the thin ship shapes at other neighboring speeds. These differences are probably not due to either calibration problems or errors in the measurements of the waveprobe position relative to the model, since these would have affected the other wavecuts similarly.

The effects on thin ship shape due to different wave probe transverse positions were examined. Figure 15 shows the optimum thin ships at $F_n = 0.279$ with transverse position (measured from the model centerline) to beam ratios (Y/B) of 2.25, 3.0, and 4.0. The difference in optimum thin ship shapes for different Y/B values are similar in size to the differences between the optimum thin ship shapes developed from repeated wavecuts. Therefore, it seems that the effects on thin ship shape due to different waveprobe transverse positions are negligible.

CONCLUSIONS

1) The optimized hull had lower C_W values than did the original hull at Froude numbers higher than $F_n = 0.275$. The optimized hull had a lower C_W value at the design F_n of 0.279, as predicted.

2) Even though the optimized hull C_R and P_E values were higher than the original hull values at the design F_n, at slightly higher values of F_n (above $F_n = 0.283$) the optimum hull performed better than the original hull. Because Baba's method only minimizes one component of residuary resistance, wave - cut, and that the effects on the other components of residuary resistance due to altering the hull are not accounted for in the predictions, it is not to be expected that the residuary resistance and P_E values would only reflect the changes in the wave - cut resistance.

3) The predicted and actual C_W curves for the optimized hull were similar, if the humps and hollows in the predicted C_W curves were smoothed. Further work is needed to examine whether the smoothing of the predicted C_W curve is a valid approach in the optimization procedure.

4) Generally, the computed thin shapes based on the initial and final series of wavecuts showed good repeatability. Further, the effects on thin ship shape due to changing the transverse position of the waveprobe relative to the model seem to be negligible.

5) Baba's method seems to have potential for optimum hull-form search, but more experience will be required to be able to use it as an effective design tool.

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3. Fisher, Steven C., "Documentation for an Improved Version of Hulimp, A Ship Hull Improvement Computer Program Based on the Baba Theory", DTNSRDC/SPD-0820-03, October 1980.

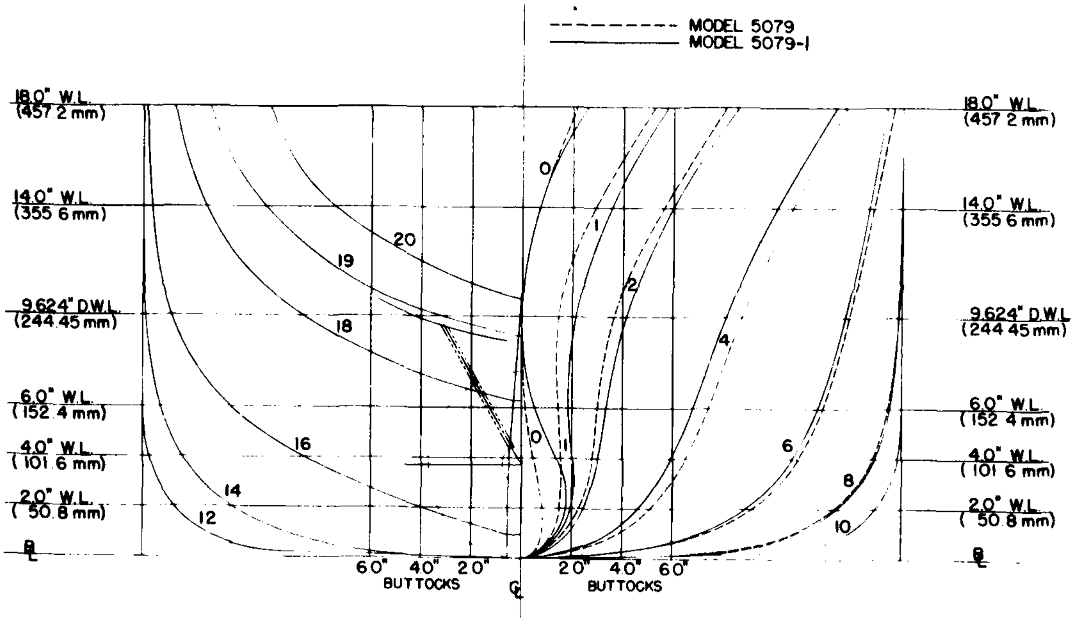
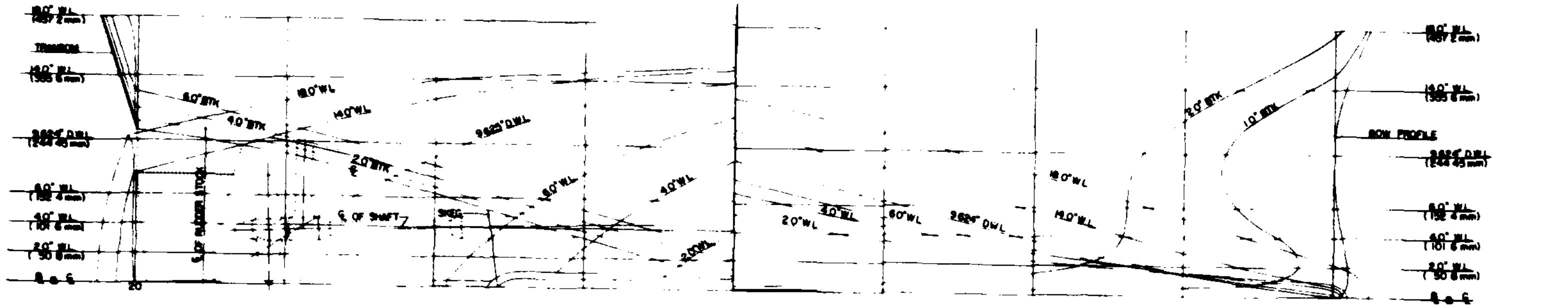
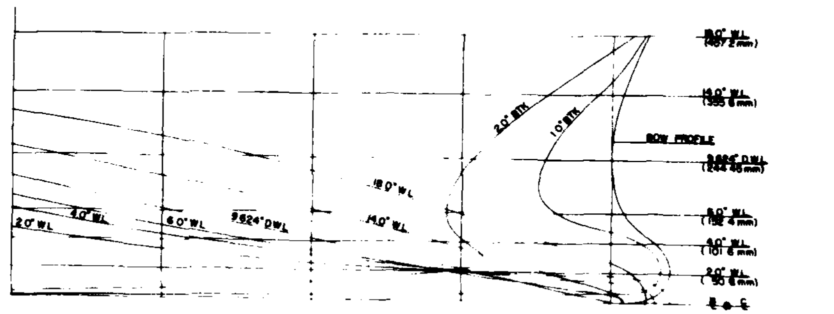


Figure 1 - Bow Lines Drawings of Model 5079 and Model 5079-1



MODEL 5079



MODEL 5079-1

Figure 1 - Bow Lines Drawings of Model 5079 and Model 5079-1 (Continued)

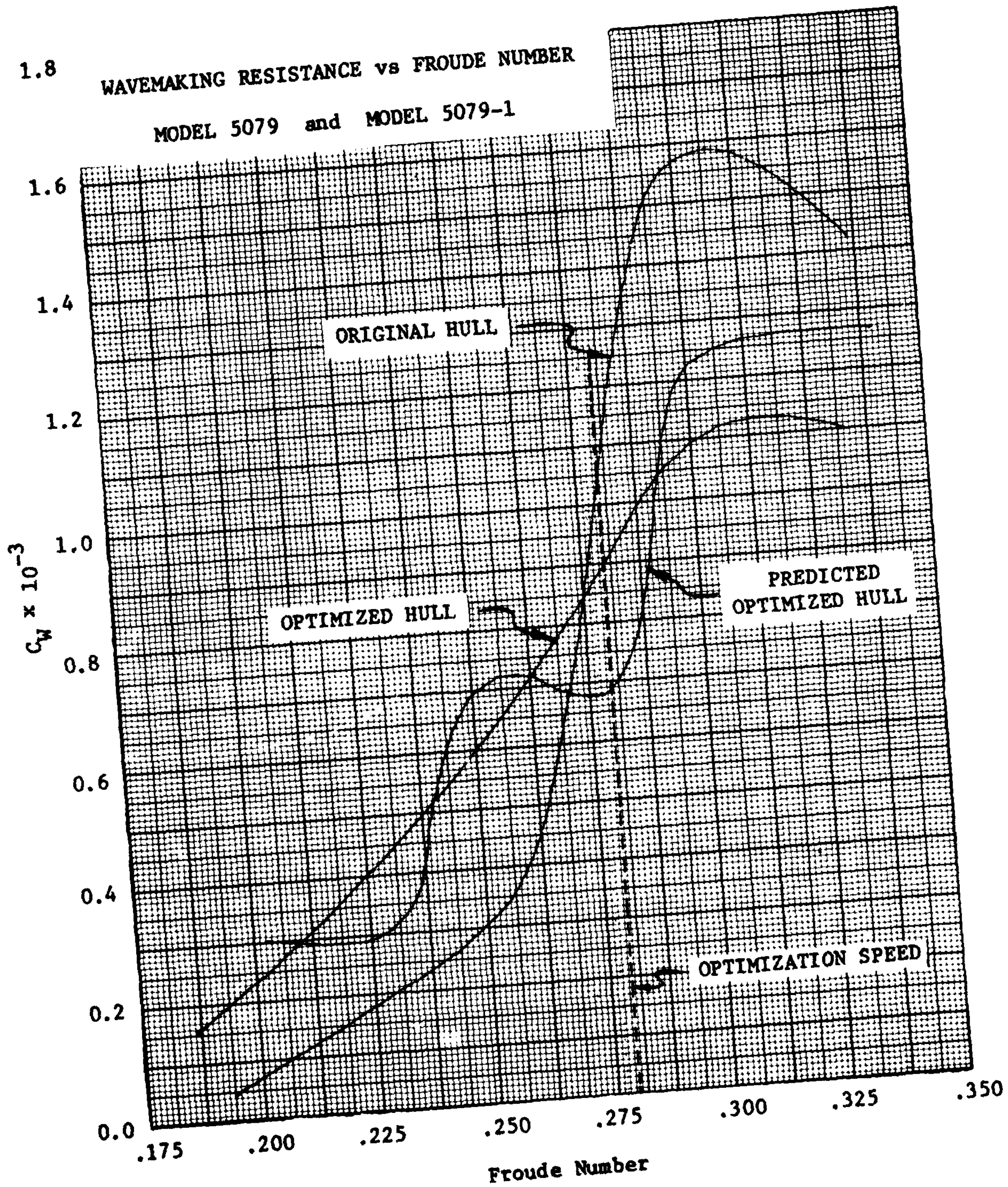


Figure 2 - Curves of C_W versus Speed for the Original and Optimized Hulls (Model 5079 and Model 5079-1)

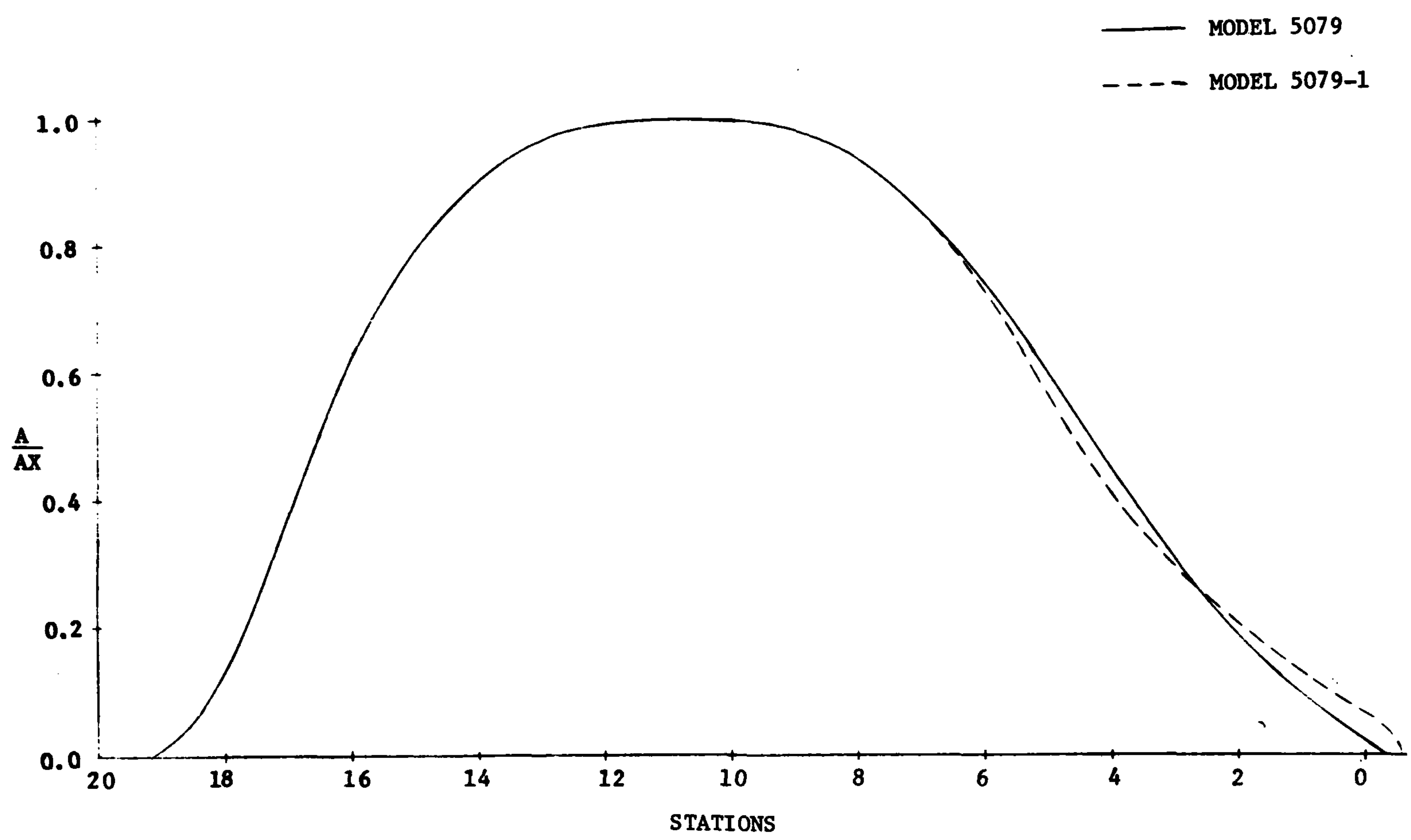


Figure 3 - Sectional Area Curves for Model 5079 and Model 5079-1

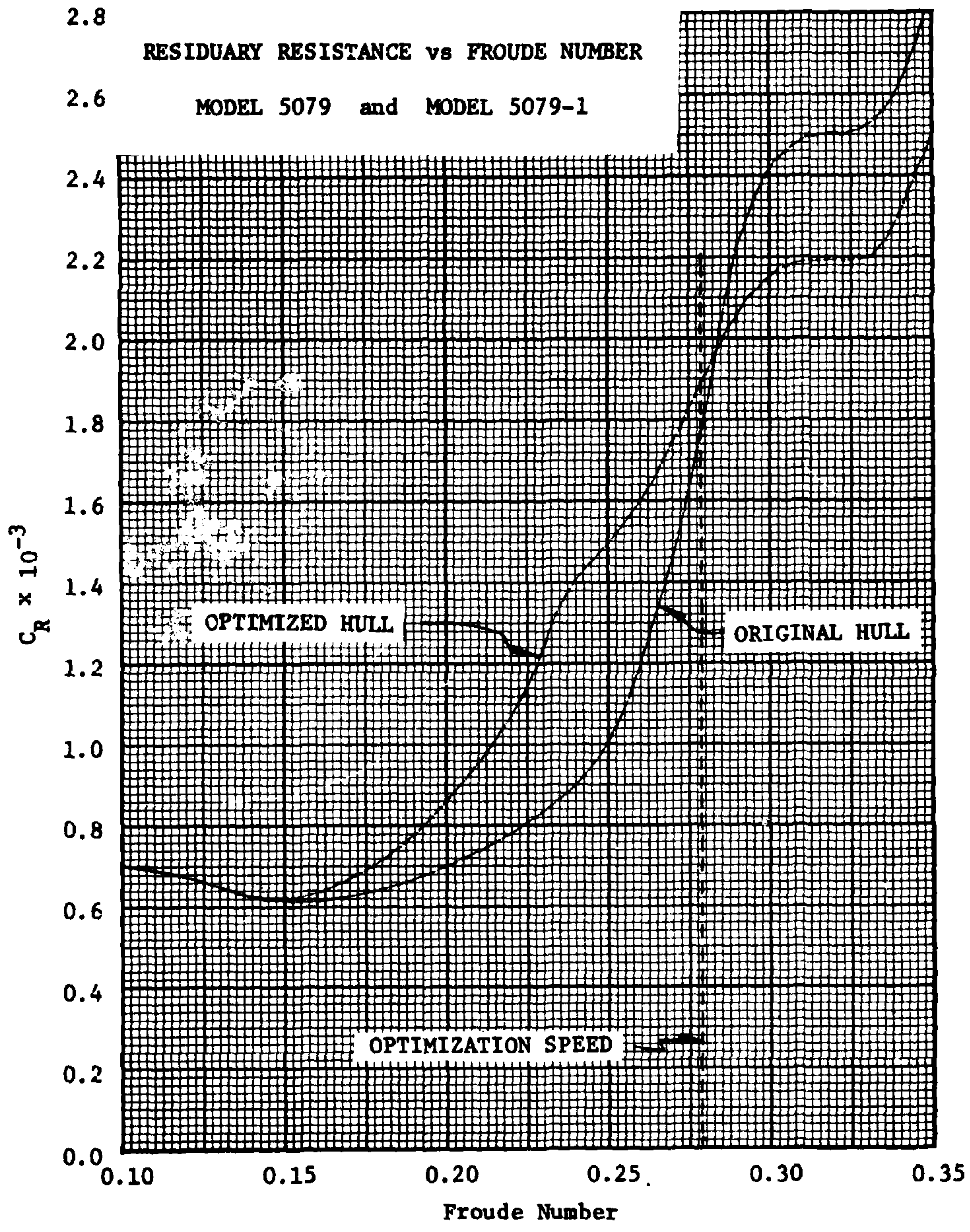


Figure 4 - Curves of C_R versus Speed for the Original and Optimized Hulls (Model 5079 and Model 5079-1)

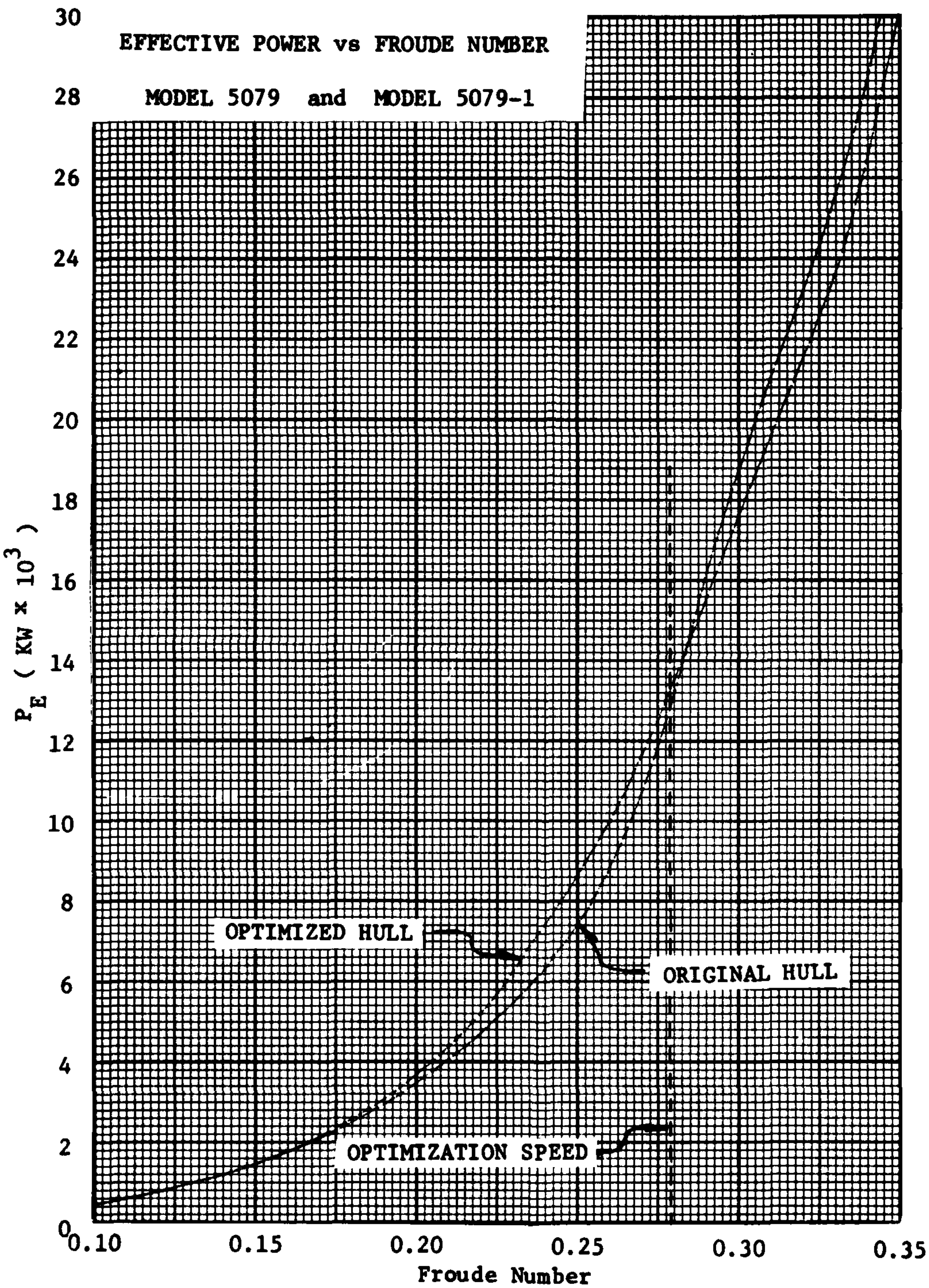


Figure 5 - Effective Power Curves for the Original and Optimized Hulls (Model 5079 and Model 5079-1)

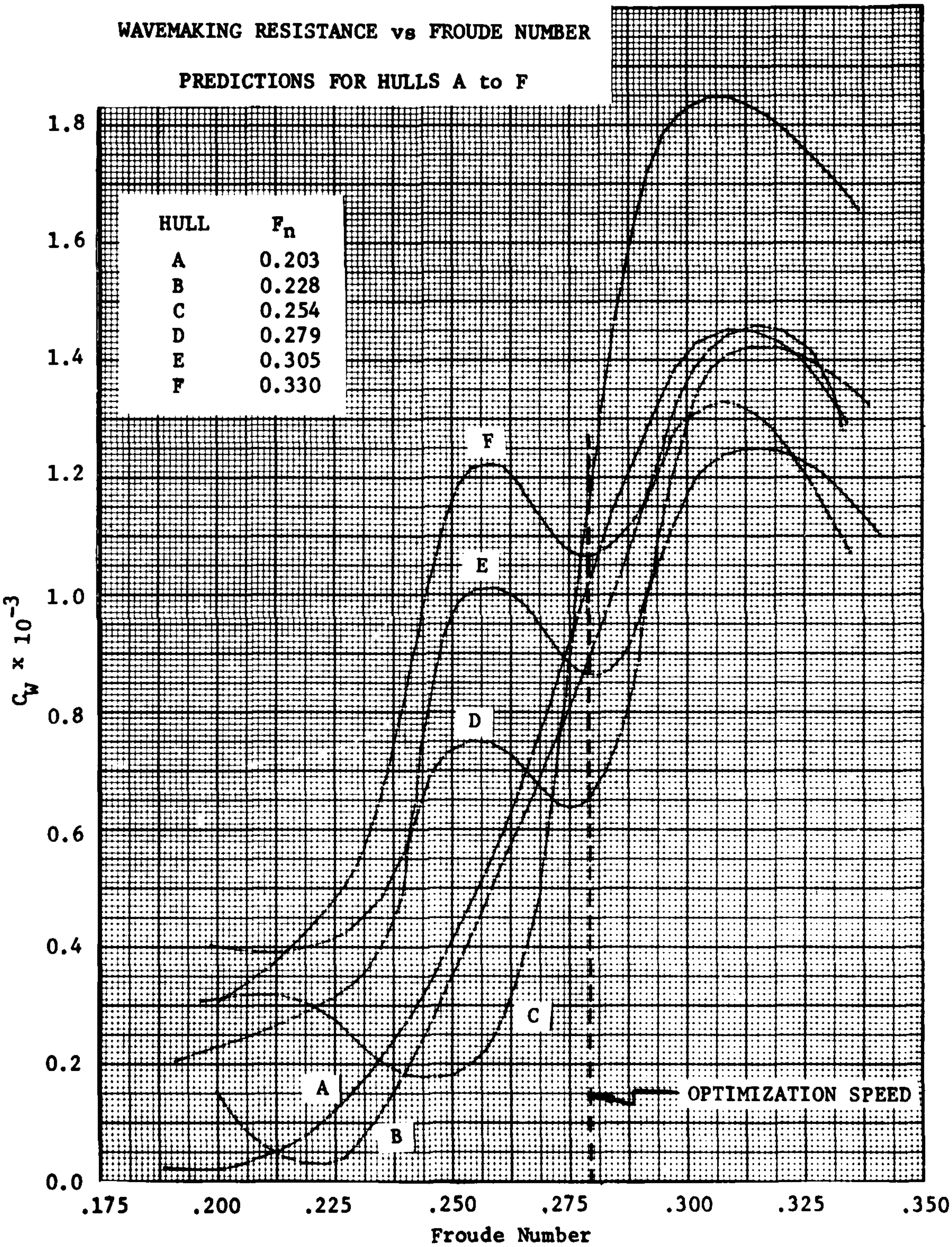


Figure 6 - Predicted C_W Curves for Hulls A to F (Optimum Thin Ship and Hull Combinations)

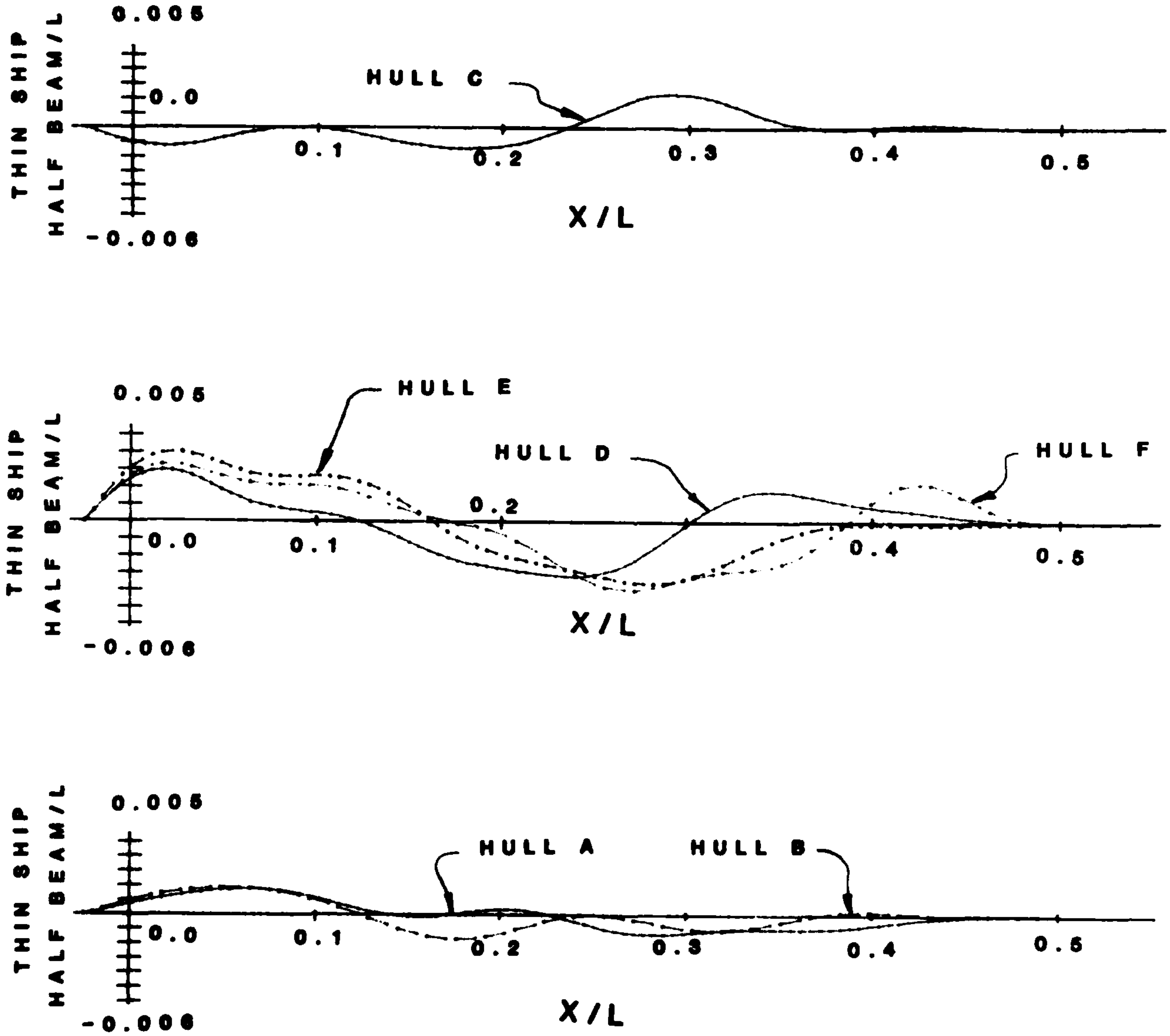


Figure 7 - Optimized Thin Ships For Hulls A to F

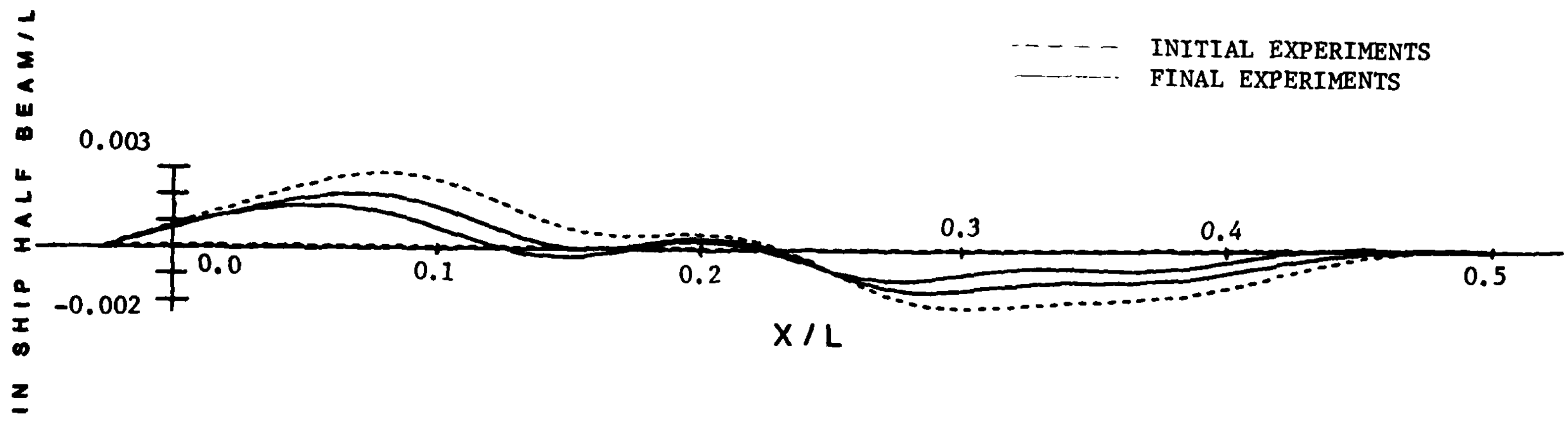


Figure 8 - Optimizing Thin Ships at Fn = 0.203

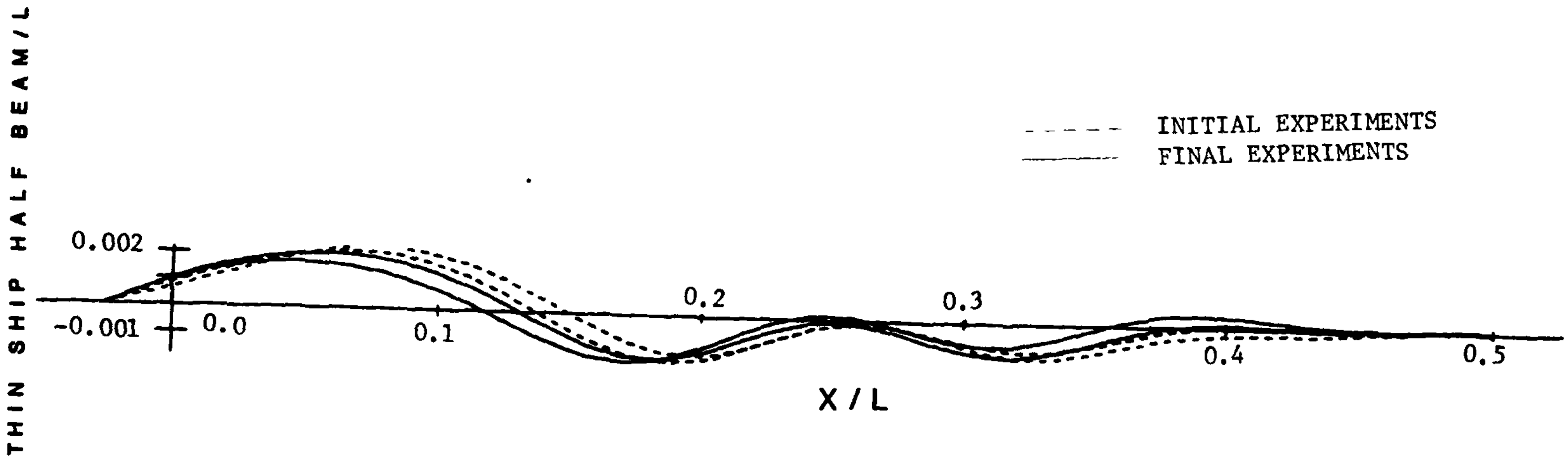


Figure 9 - Optimizing Thin Ships at Fn = 0.228

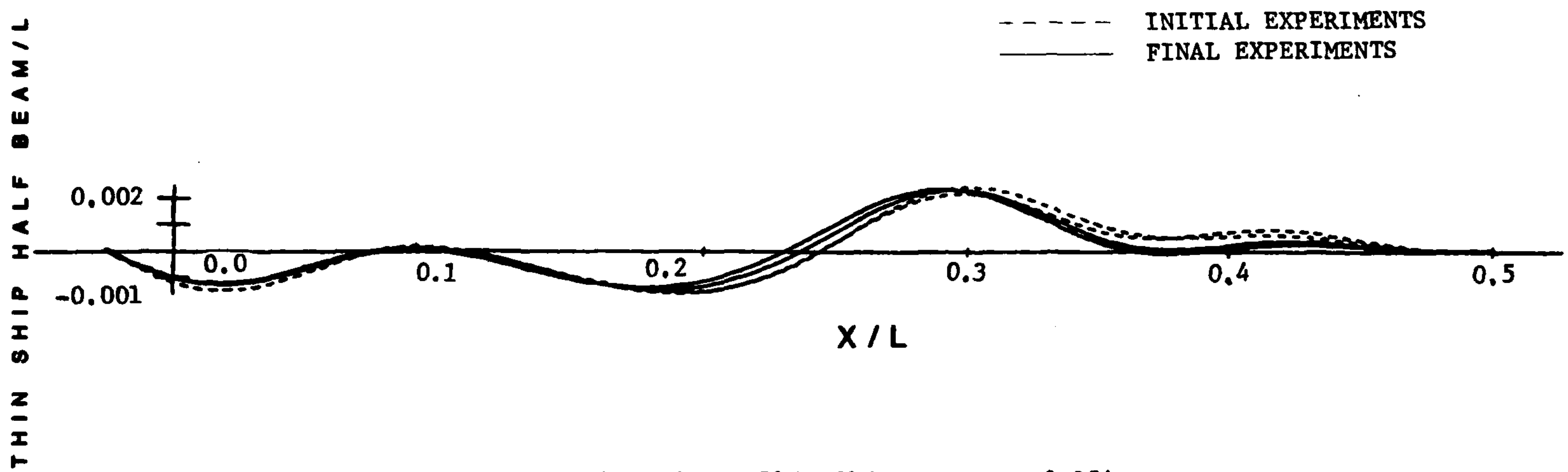


Figure 10 - Optimizing Thin Ships at Fn = 0.254

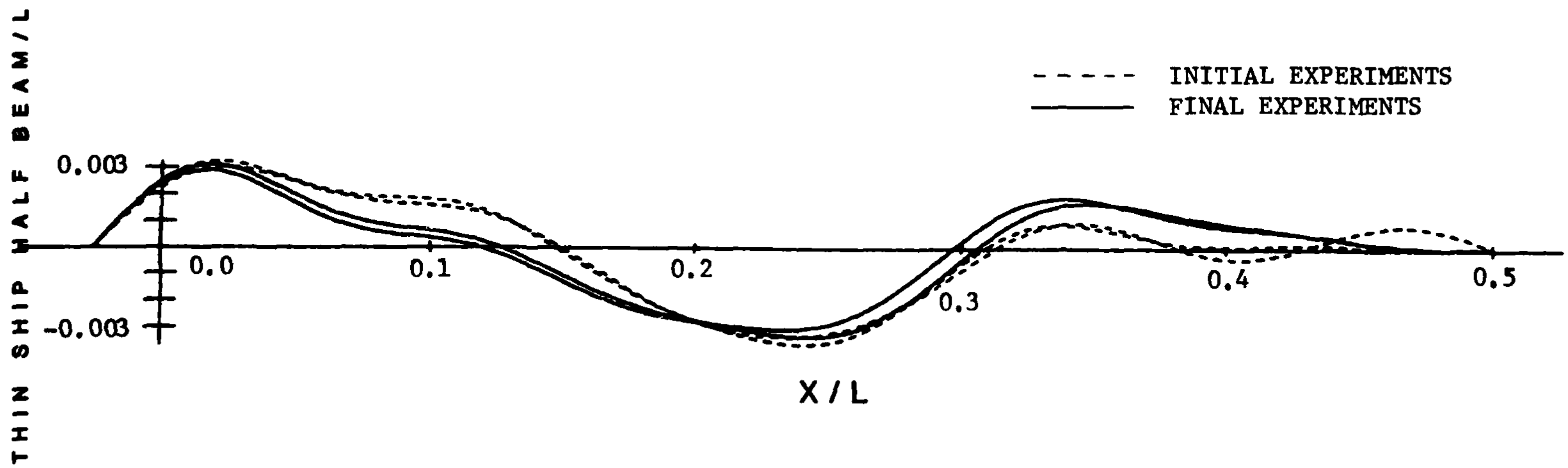


Figure 11 - Optimizing Thin Ships at Fn = 0.279

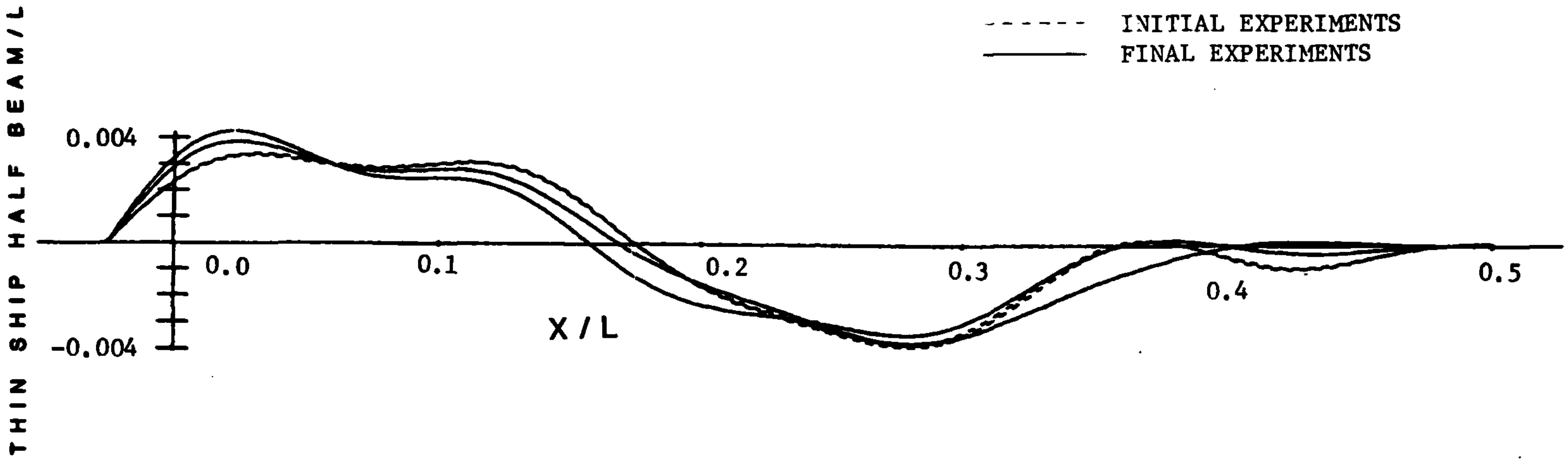


Figure 12 - Optimizing Thin Ships at Fn = 0.305

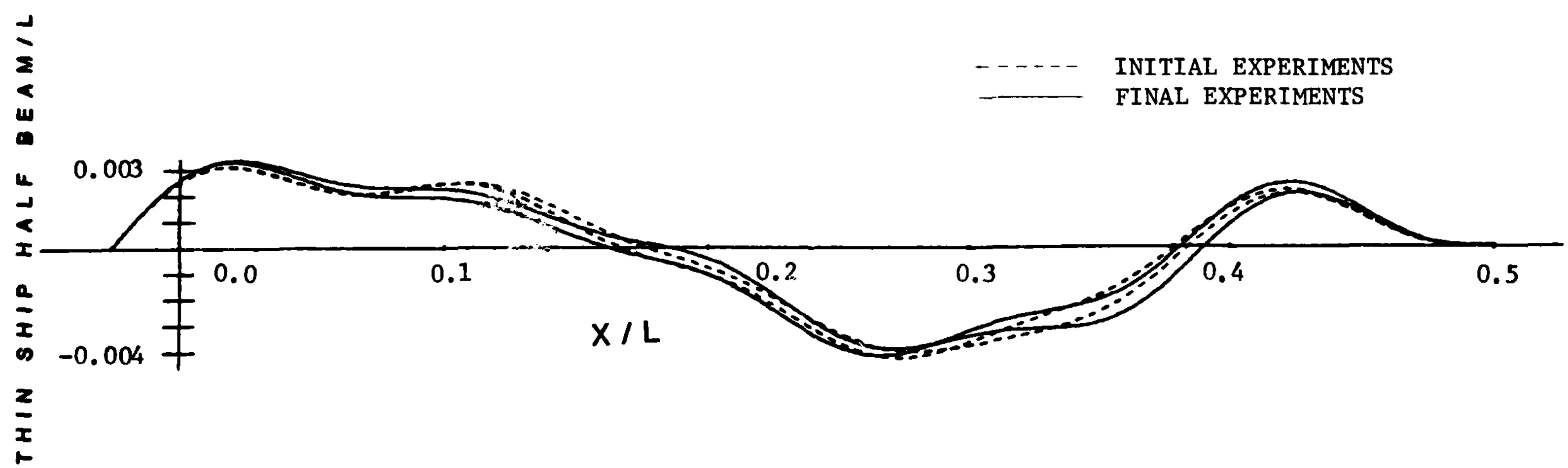


Figure 13 - Optimizing Thin Ships at Fn = 0.330

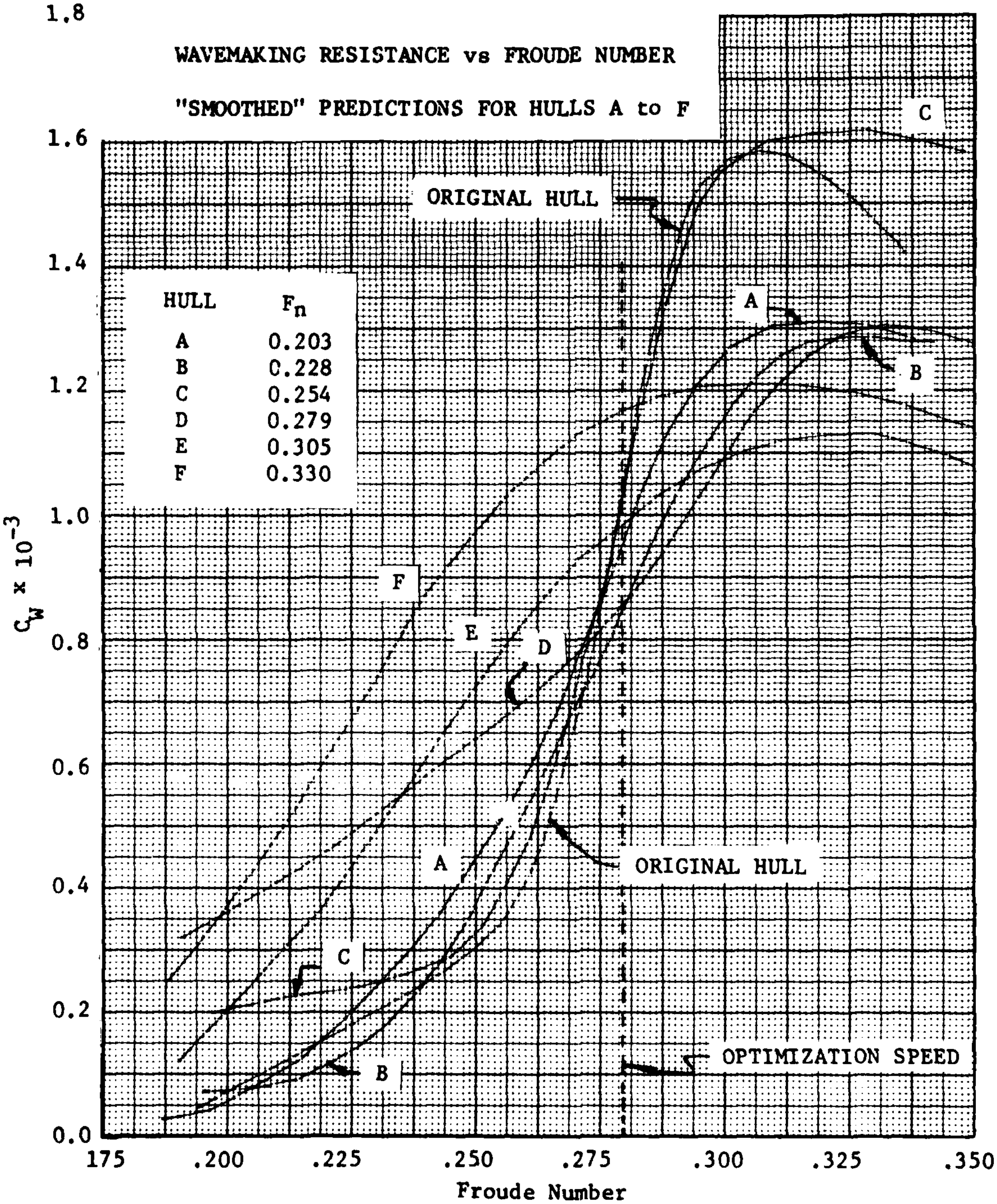


Figure 14 - Smoothed Predicted C_W Curves for Hulls A to F (Optimum Thin Ship and Hull Combinations)

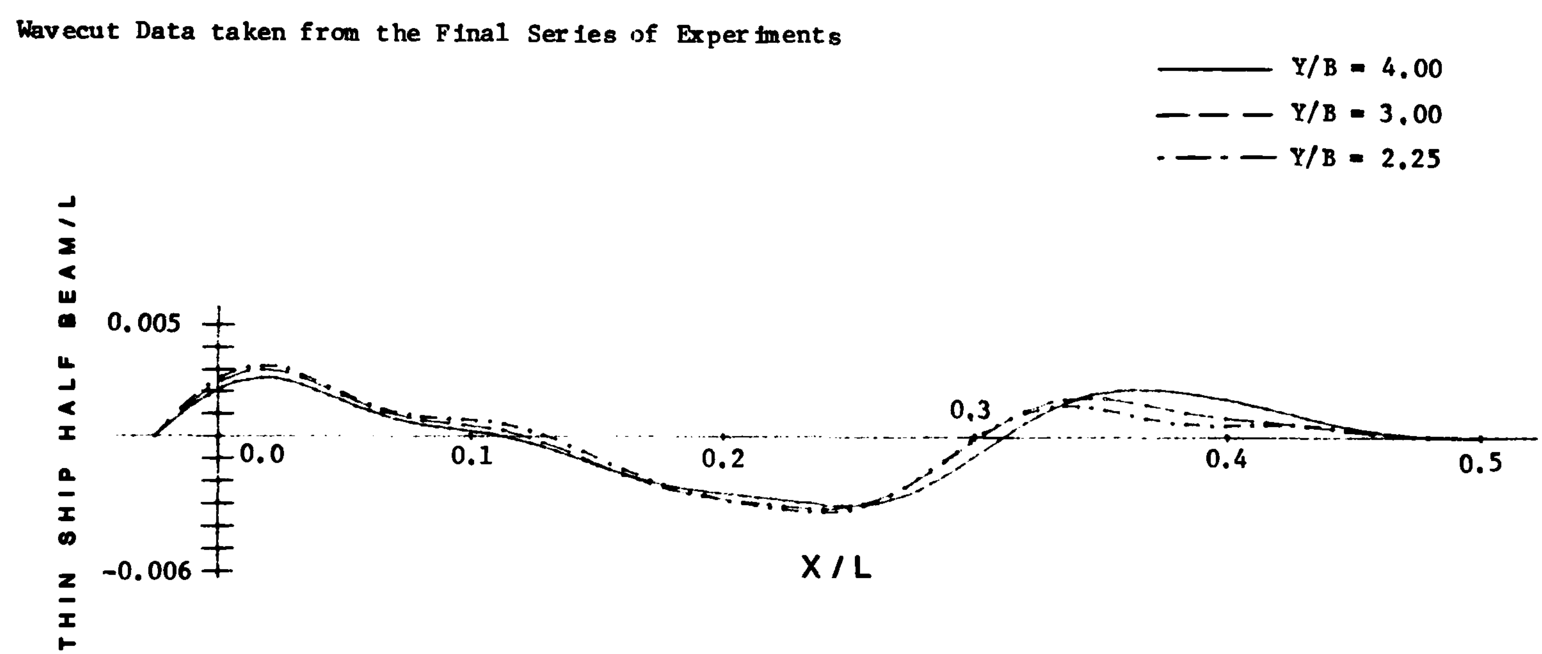


Figure 15 - Optimum Thin Ships at $F_n = 0.279$ with the Wave Probe at Various Transverse Positions

TABLE 1
PRINCIPAL DIMENSIONS OF AKA 113 AND MODELS 5079 AND 5079-1

	MODEL 5079		MODEL 5079-1		AKA 113		5079-1 SHIP	
Length	5.158 m	16.923 ft	5.158 m	16.923 ft	167.6 m	550 ft	167.6 m	550 ft
Beam	0.769 m	2.523 ft	0.769 m	2.523 ft	24.99 m	82 ft	24.99 m	82 ft
Draft	0.244 m	0.802 ft	0.244 m	0.802 m	7.95 m	26.07 ft	7.95 m	26.07 ft
C_B	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567
Displacement	0.548 t	0.540 tons	0.548 t	0.540 tons	19360 t	19050 tons	19370 t	19060 tons
Wetted Surface	4.301 m^2	46.30 ft^2	4.306 m^2	46.35 ft^2	4543 m^2	48900 ft^2	4548 m^2	48960 ft^2

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